AN ASTROPHYSICS DATA PROGRAM INVESTIGATION OF HEAO-2/EXOSAT DATA — AN ANALYSIS OF THERMAL X-RAY EMISSION FROM SUPERNOVA REMNANTS

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The goal of the project was the study of the thermal X-ray spectra of supernova remnants (SNRs) including nonequilibrium ionization (NEI) effects in a model-independent manner. The data for the study were extracted from archival sources and came from instruments onboard *Einstein*, EXOSAT, and *Tenma*. A number of important scientific results were obtained and they are summarized below. The most important aspect of the study was the development of the NEI spectral model and the demonstration that it provided an excellent fit to the data from SNRs in various different phases of evolution.

The spectral model coupled a nonequilibrium ionization calculation with the plasma emission code of Raymond and Smith (1977 and subsequent revisions). The ionization calculation was based on the matrix solution developed by Hughes and Helfand (1985), although the actual code to perform the diagonalization and determine the eigenvectors was completely re-written to improve the accuracy and increase the robustness of the solution. The complement of emission lines in the Raymond and Smith code was supplemented by a number of lines from Mewe and Gronenschild (1981) which were appropriate to the NEI situation. In particular it necessary to include Kα transitions from low ionization states of the astrophysically abundant elements as well as emission from innershell ionization processes. The model also includes continuum emission from bremsstrahlung, radiative recombination, and two-photon emission. For computational reasons a large grid of models in the $\tau - T$ plane was precomputed, keeping the emission from the astrophysically abundant elements (H, He, C, N, O, Ne, Mg, Si, S, Ar, Ca, Fe, and Ni) separate in order to allow subsequent adjustment of the elemental abundances. A scheme was developed which eliminates the problem of choosing a model grid, which arises in the joint analysis of multi-mission broadband X-ray data. Usually a fine binning in energy is used in the precomputed model and then interpolated for the various energy binnings required by the various instruments. This tends to smear sharp lines into several bins. The solution was to store the emission lines separately from the continuum. The continuum, which varies smoothly with energy, can be interpolated rather accurately onto the various grids corresponding to different instruments. At this point in the fitting routine the emission lines are put into the proper energy bins as well.

The model has provided acceptable fits to a wide variety of data for SNRs. For the oxygen-rich SNR G292.0+1.8, we determined the abundances of the elements O, Ne, Mg, Si, S, Ar, and Fe and compared them to predictions of nucleosynthesis in massive stars (Thielemann *et al.* 1990). We find excellent agreement with the nucleosynthetic yield from a 25 $M_\odot$ progenitor (a minimum RMS difference between the model abundances and data of $\sim$ 8%). This is the first time, to our knowledge, that such an excellent level of agreement between models and data has been obtained. In our work on the SNR N132D in the Large Magellanic Cloud, we were able to show that the derived elemental abundances were consistent with the lower than cosmic abundances known to be present in the LMC and could include, as well, a component due to massive star nucleosynthesis. A comparative study of the spectra of Tycho, SN1006, and Cas A was used to show that that the ejecta of Type I SN explosions (which Tycho and SN1006 are believed to be) are not fully mixed during the early evolution of the SNR, while the ejecta of Type II explosions (such as Cas A) are. This study was based on an analysis of the centroids of the Kα lines from Si, S, Ar, Ca, and Fe. This result is consistent with current models for Type I and II SN explosions, the observation of significant mixing in the ejecta of SN1987A (which was a Type II), and the lack of significant mixing in other SN of Type I (although none of these have been as well studied as SN1987A). G292.0+1.8, which apparently was the product of a Type II SN explosion based on the mass of its progenitor, also seems to have been rather heavily mixed during its early evolution, like Cas A.

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